Commissioning of positron timing counter for MEG II experiment

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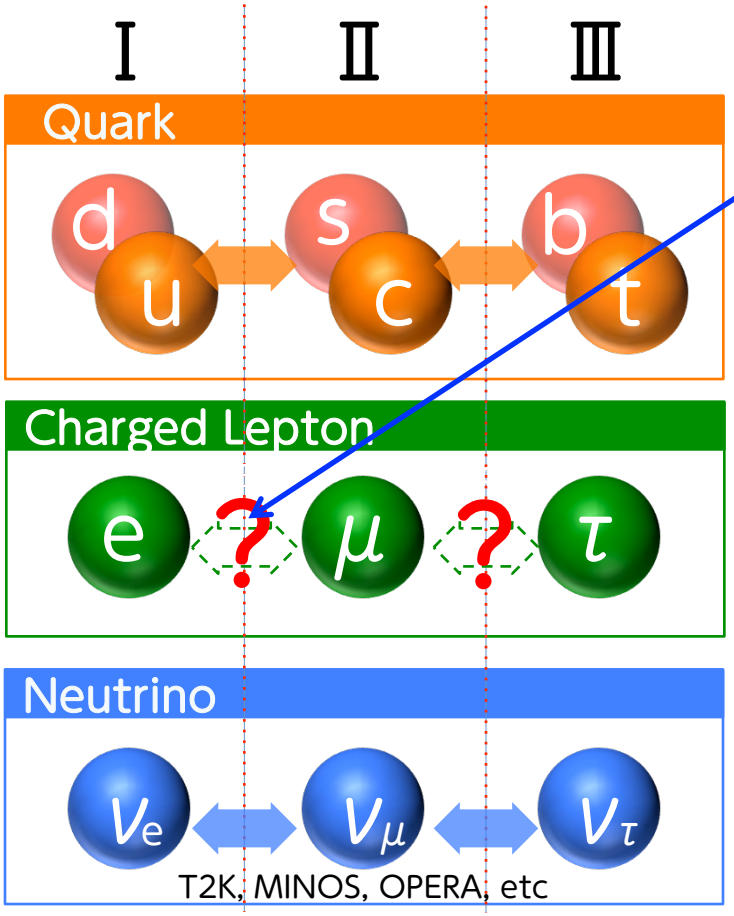
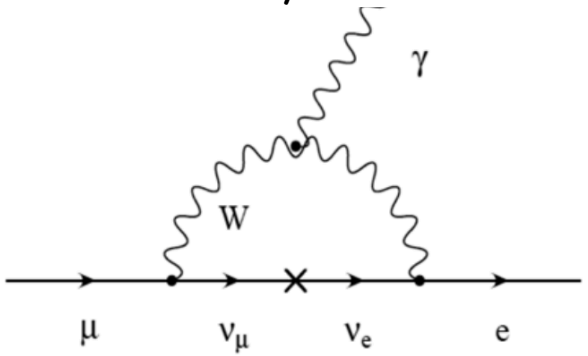
$\mu^+ \to e^+ \gamma$ and ν oscillation

(Nobel Prize 2015) http://www.nobelprize.org/



- Charged lepton flavour violation is still undiscovered.
- Br($\mu^+ \to e^+ \gamma$) with neutrino oscillation is very low.



$$\mathcal{B}(\mu \to e\gamma) = \frac{3\alpha}{32\pi} \left| \sum_{i=2,3} U^*_{\mu i} U_{ei} \frac{\Delta m^2_{i1}}{M^2_W} \right|^2 \simeq 10^{-54}$$

- BSM(SUSY-GUT etc.) predicts larger Br=$O(10^{-12})$~$O(10^{-14})$

The discovery of cLFV = New Physics!!

T. Mori, W. Ootani / Progress in Particle and Nuclear Physics 79 (2014) 57–94

ATLAS vs MEG

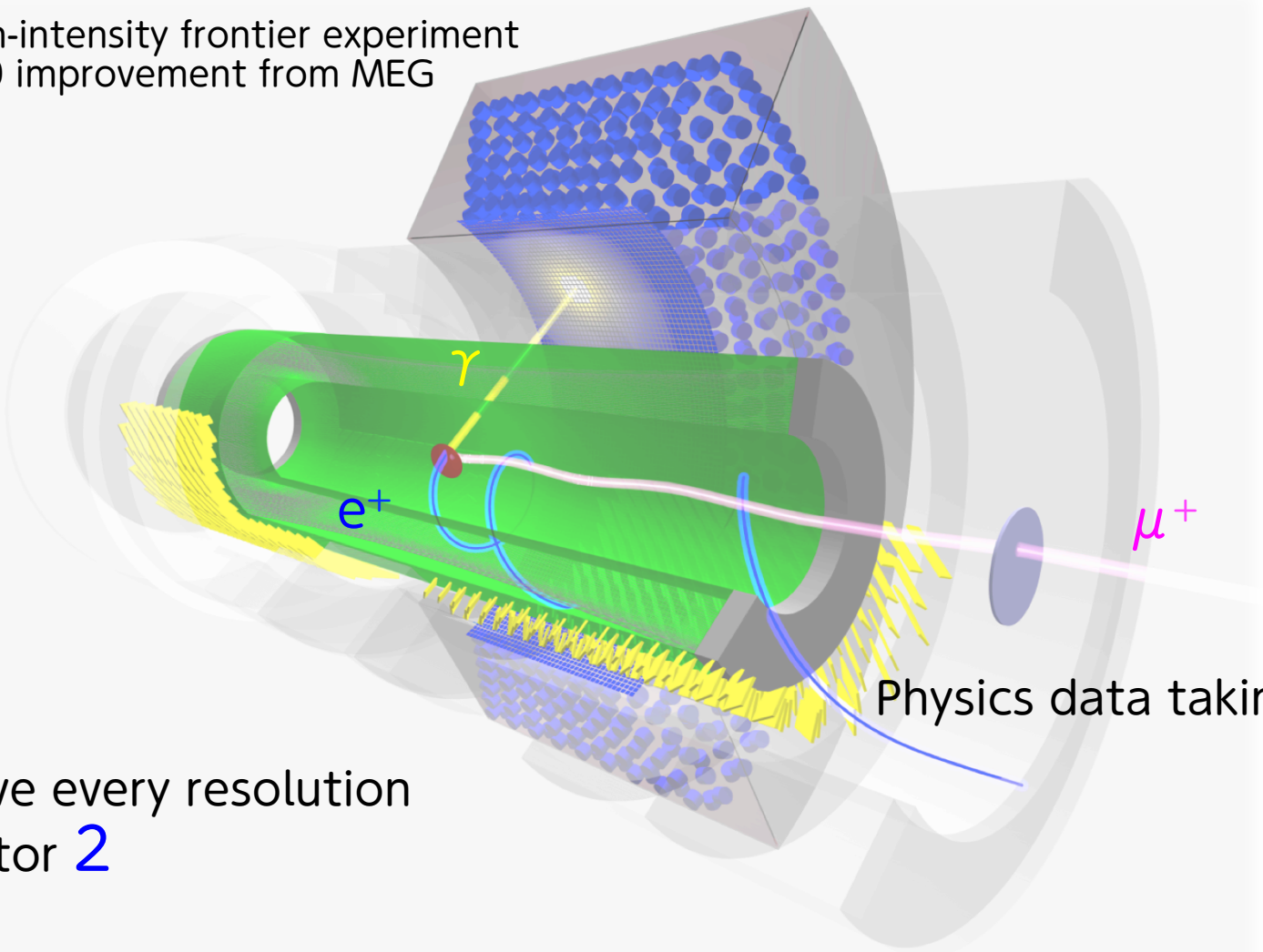
地図はGoogle Mapより、ロゴは各研究所HPより引用

MEGII Experiment: 3 numbers

1 Search for cLFV($\mu^+ \to e^+ \gamma$)

with unprecedented sensitivity: 4×10^{-14}

- ✓ High-intensity frontier experiment
- ✓ x 10 improvement from MEG



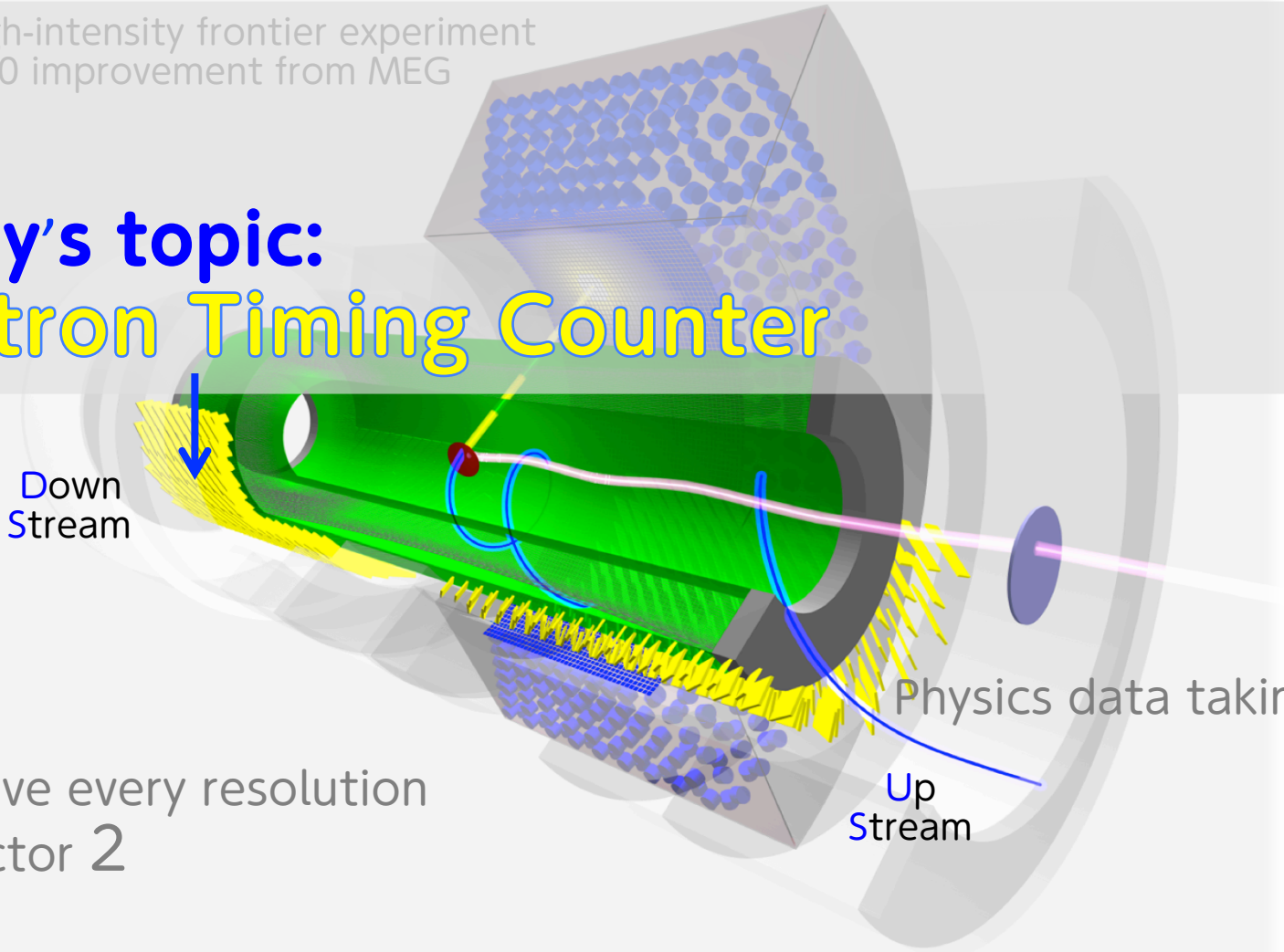
2 Improve every resolution by factor 2

3 Physics data taking from 2017

MEGII Experiment: 3 numbers

1. Search for cLFV($\mu^+ \to e^+ \gamma$)
   with unprecedented sensitivity: 4×10^{-14}
   - ✓ High-intensity frontier experiment
   - ✓ x 10 improvement from MEG

Today's topic:
Positron Timing Counter

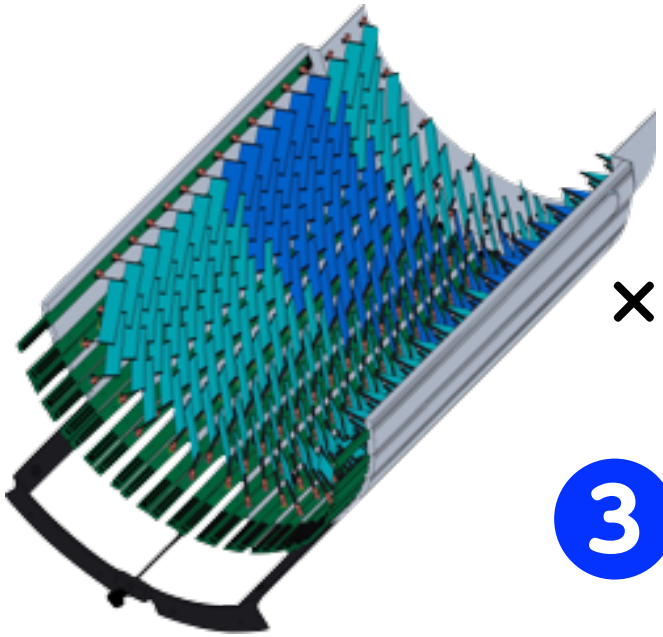


2. Improve every resolution by factor 2

3. Physics data taking from 2017

Numbers in Positron Pixelated Timing Counter

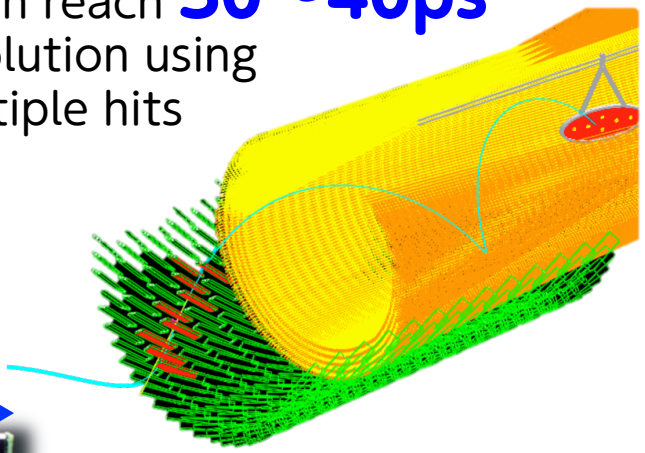
1 **512** pixelated scintillator counters



×2

2 **9** counter hits

→can reach **30~40ps** resolution using multiple hits



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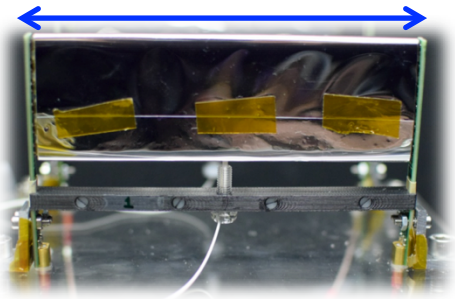


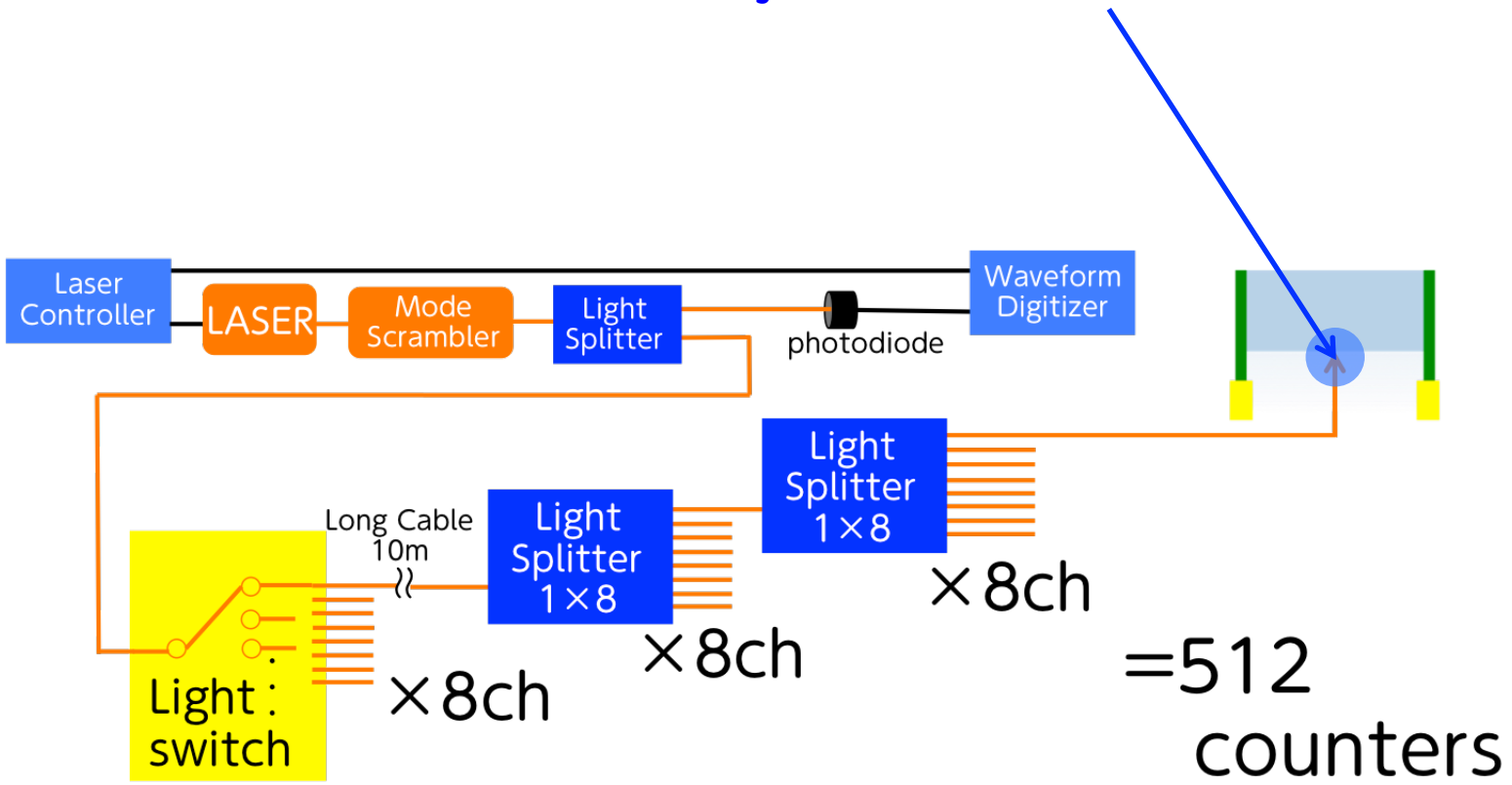
- ✓ Fast Plastic Scintillator(BC422)
- ✓ More than **6144** SiPMs(AdvanSiD)
- ✓ **6** series at the both ends
- ✓ Calibration Accuracy **30ps** w/ each counter by using pulse laser and Michel decay positron

Time Calibration by Using Pulse Laser

- In order to know timeoffset of each counter, we plan to divide the same laser into each counter.

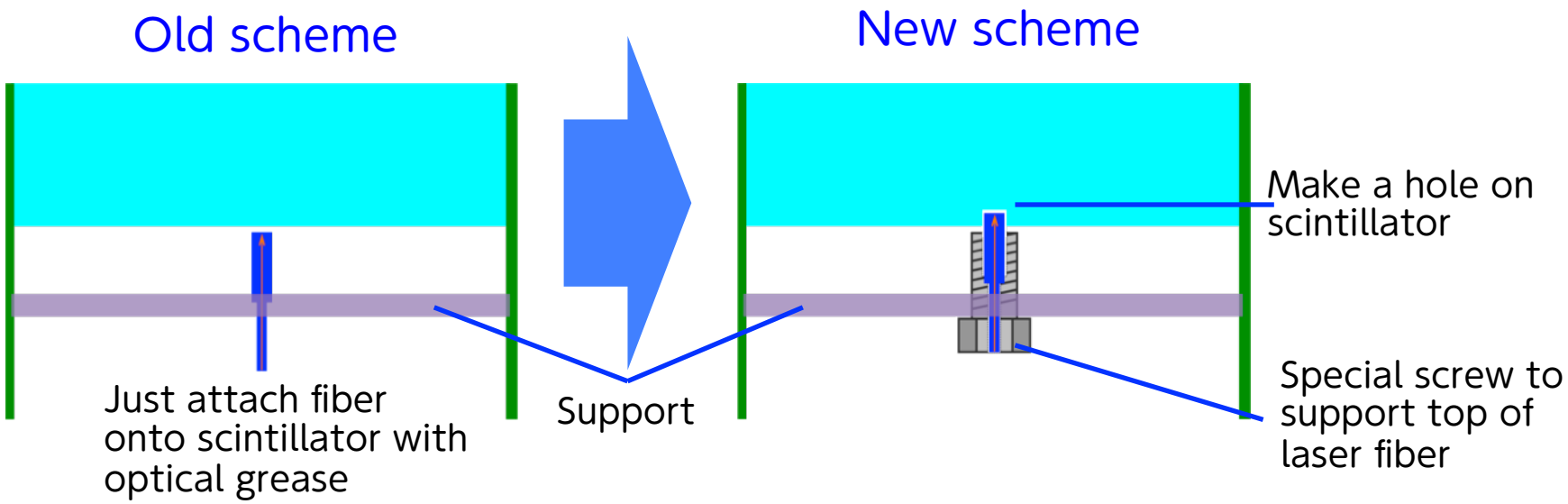
- What enables 30ps time calibration?

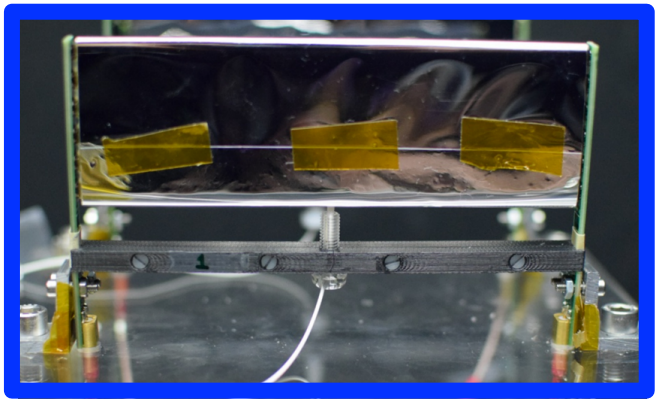
→ Laser Injection Scheme



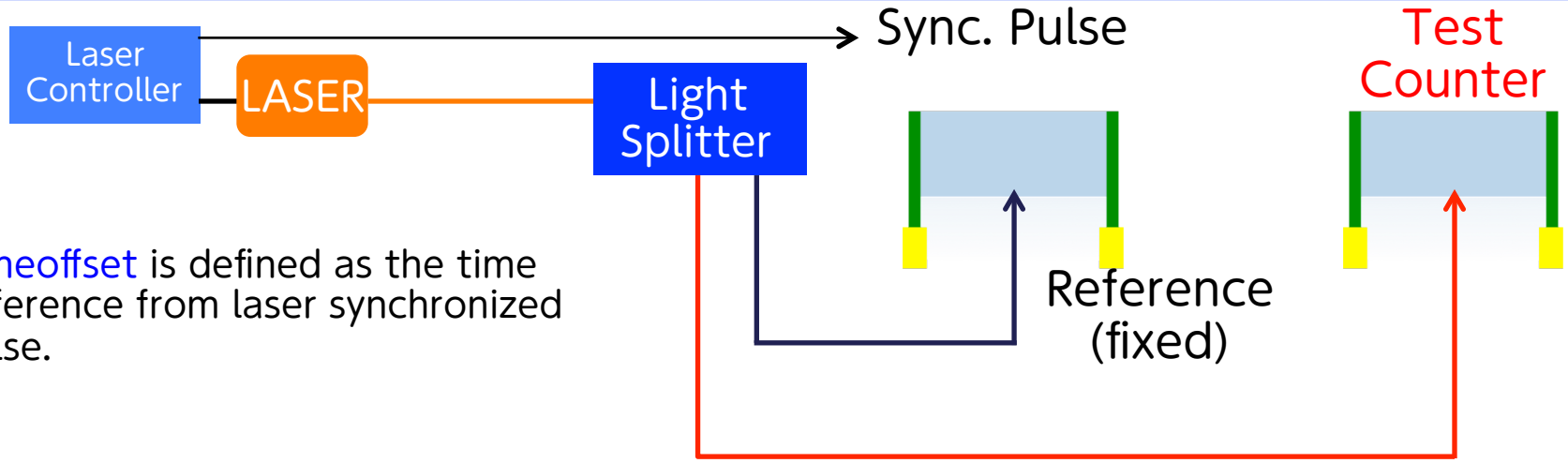
Improvement in Reproducibility

- Reproducibility on timeoffset of laser insertion scheme is required because we have to inject and eject fiber during the operation





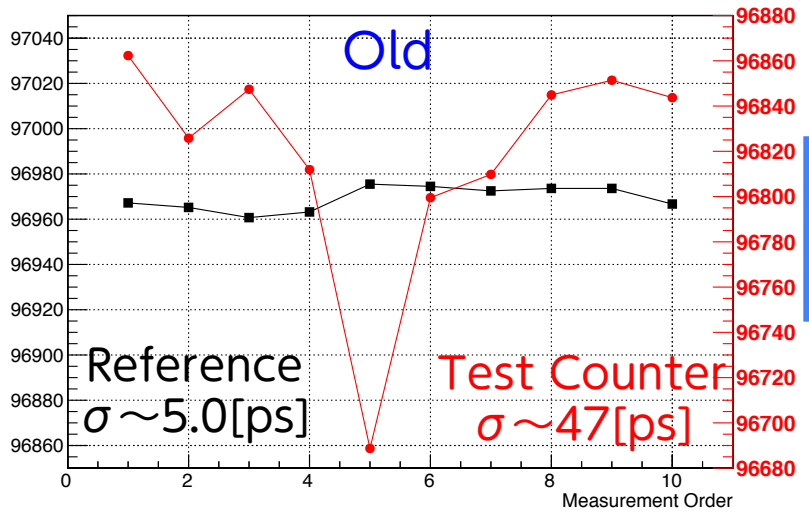
Setup & Results

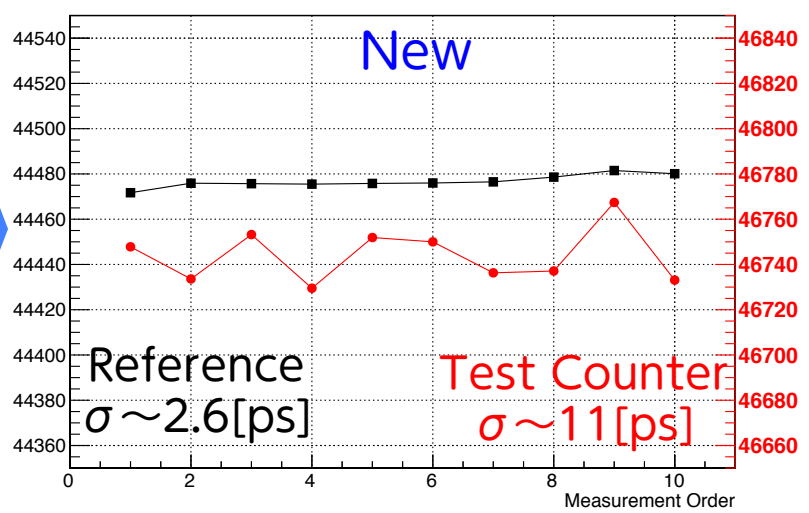


Timeoffset is defined as the time difference from laser synchronized pulse.

Timeoffset[ps]

※Scale is the same



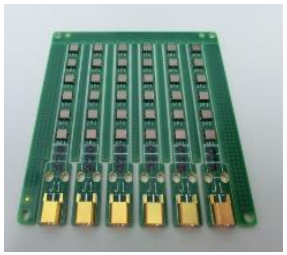


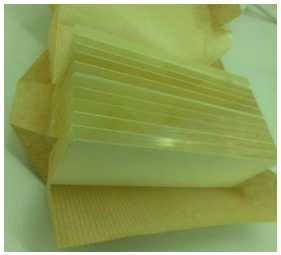
- New scheme achieved required accuracy(30[ps])

Construction

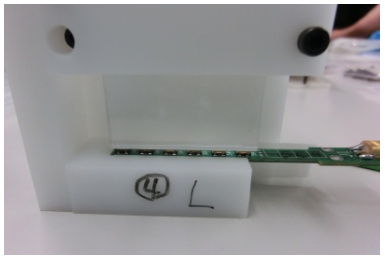
- Counter assembly

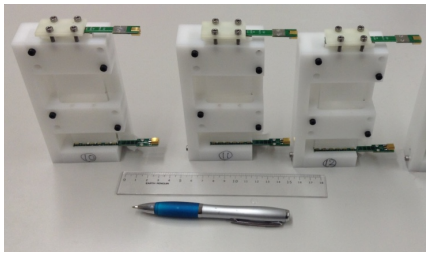
SiPMs on PCB & Scintillators





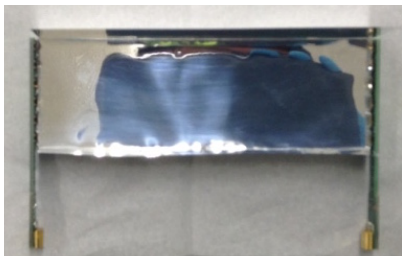
Couple scintillators and arrays w/ optical cement



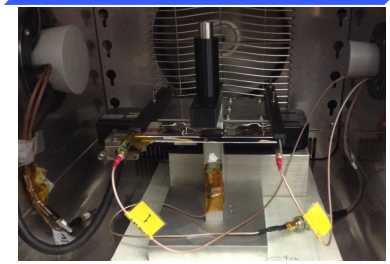


Hole making

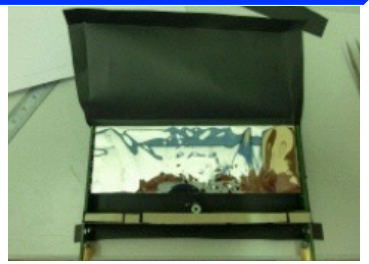
Wrap pixel with reflector

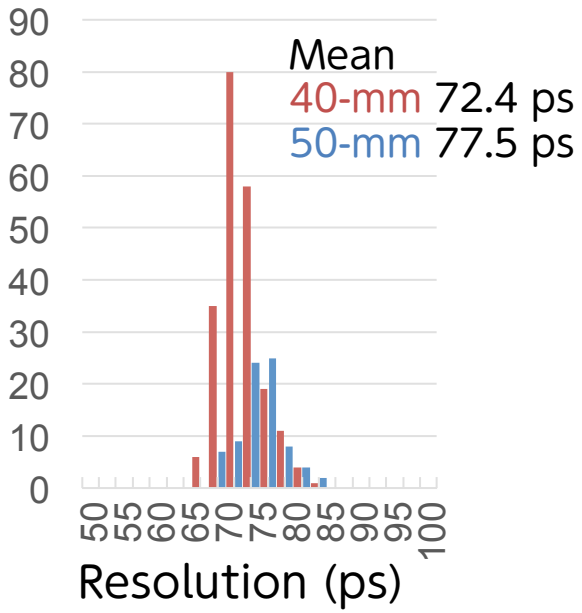


Counter Test



Shielding

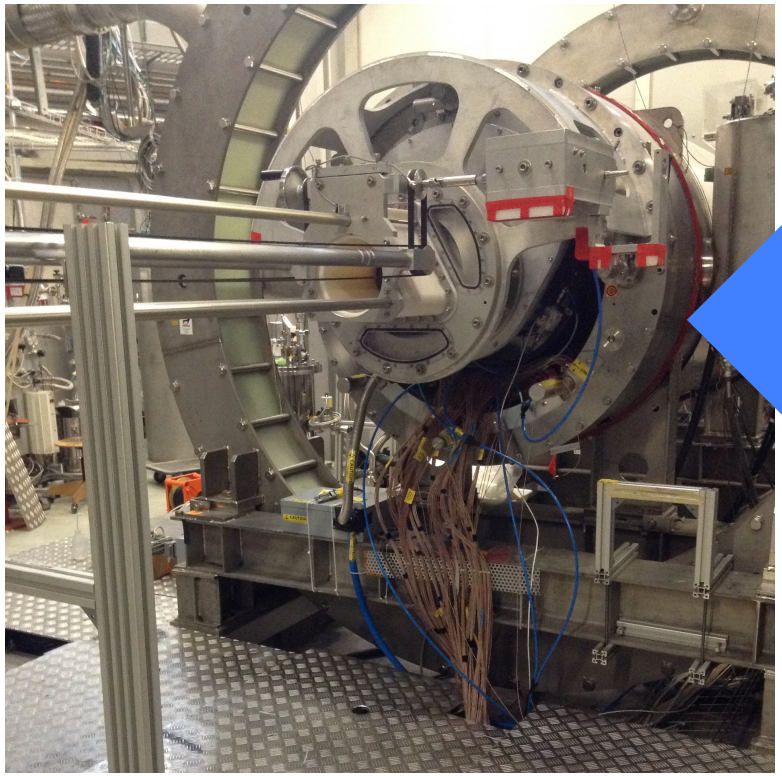




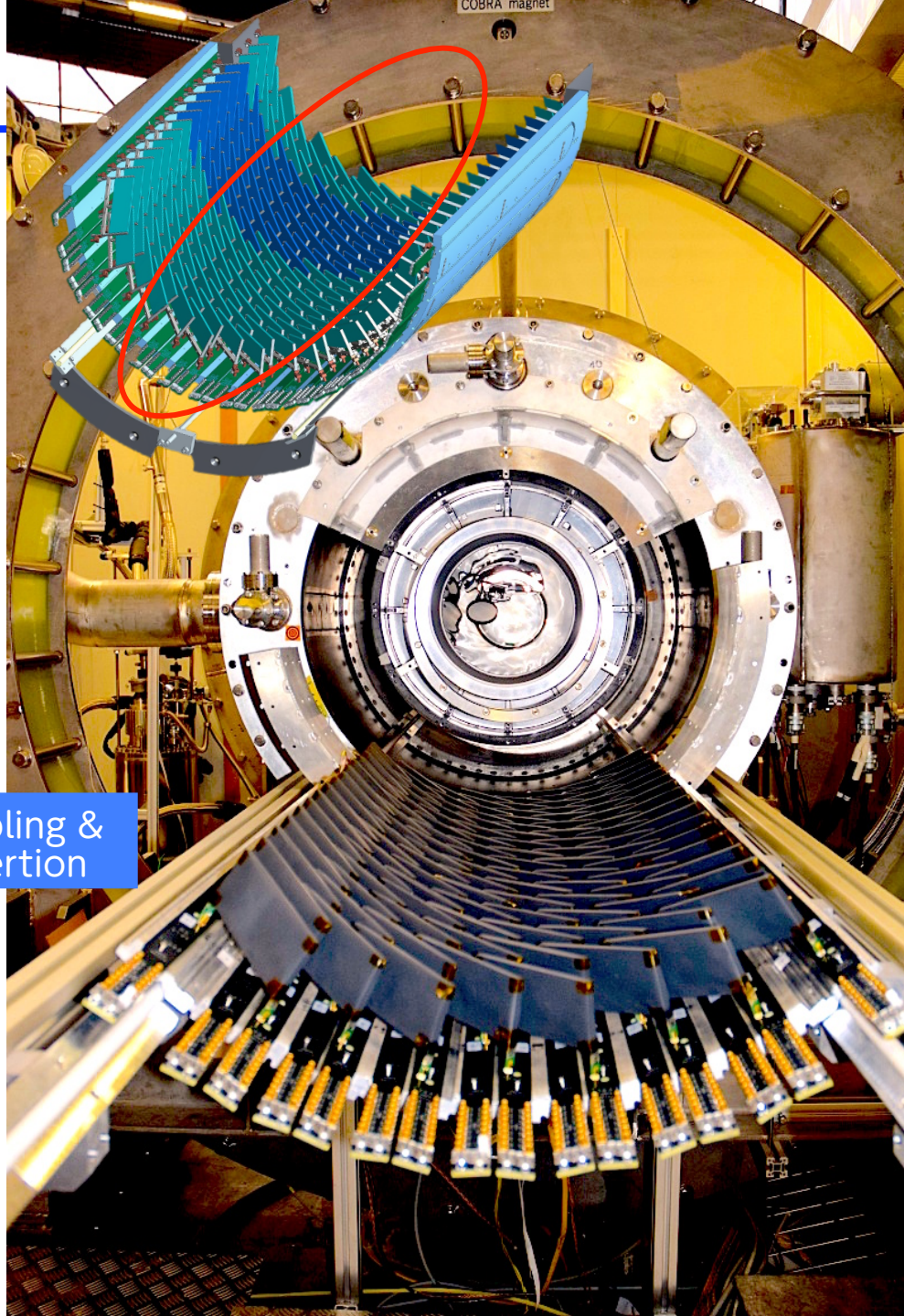
- **300** counters are produced and tested(Feb.2016)

Installation

128 Counters are installed for Pilot Run 2015

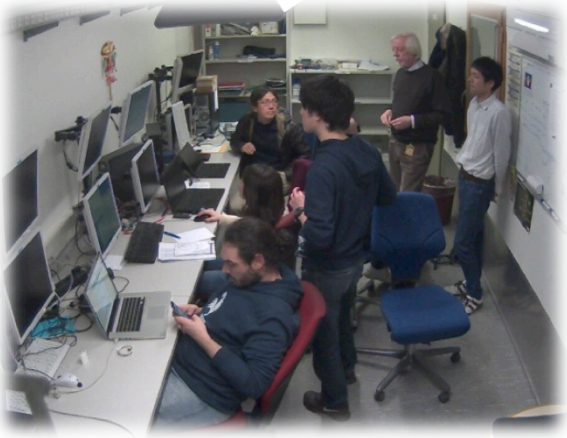


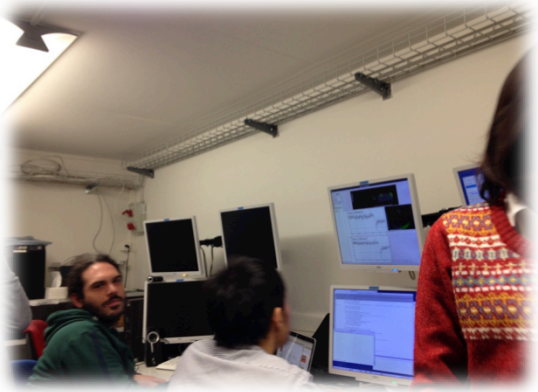
Cabling & Insertion



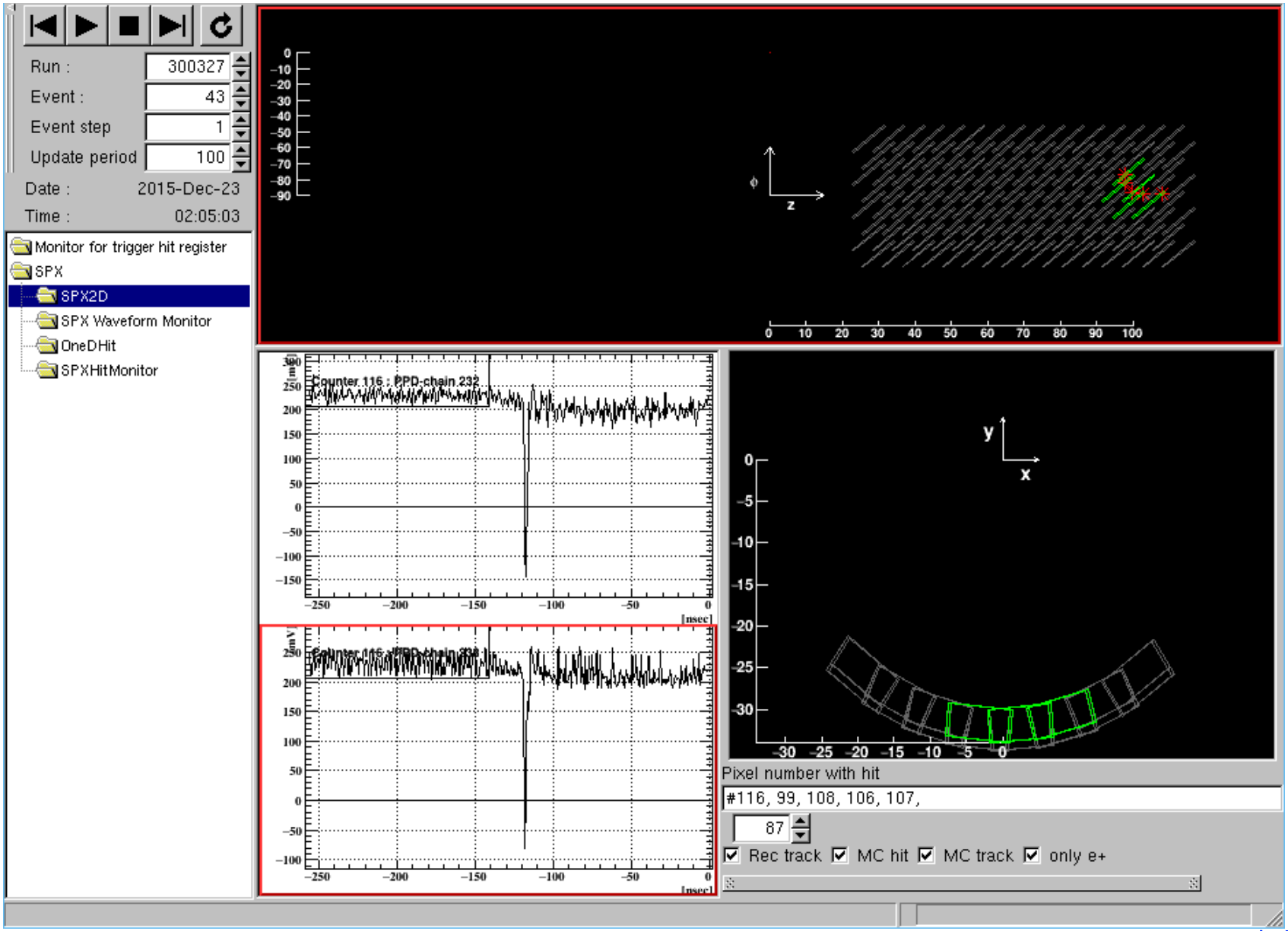
Goals of Pilot Run 2015

- Detector
  - Build ¼ detector
  - Functionality of TC hardware
  - Performance study vs. rate
- Electronics
  - Test of integrated HV system
  - Implementation of various trigger schemes
  - Waveform & noise check
  - Recording of waveform data
- Laser Calibration System
  - Implementation of laser calibration system
  - Evaluate the accuracy of laser calibration system
- And ……
  - To find unexpected problems towards physics run

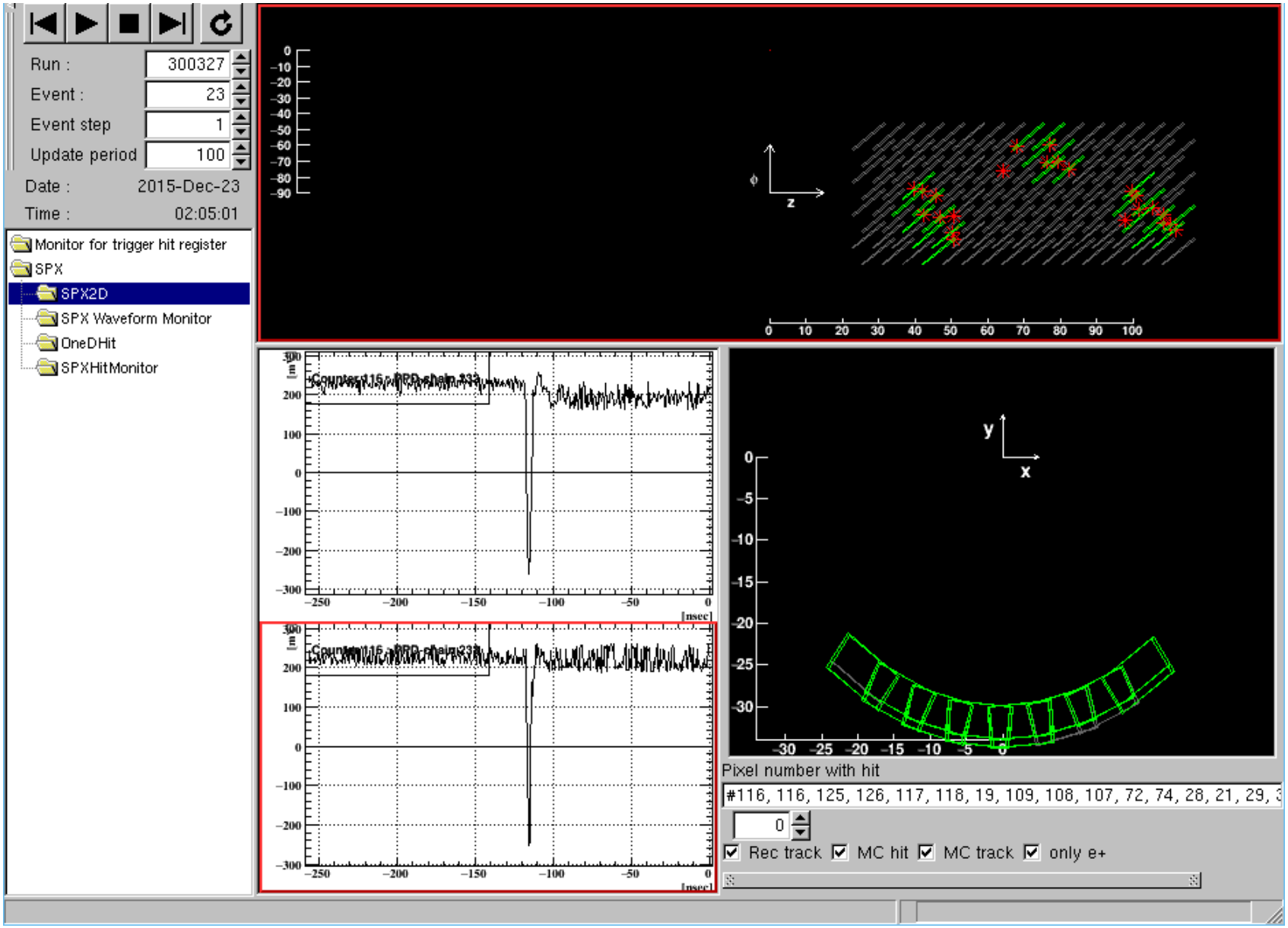




Typical clean event with multiple hits



Event with multiple clusters



Goals of Pilot Run 2015 Dec.

- Detector
- ☑ Build ¼ detector
- ☑ Functionality of TC hardware → No dead channel
- ☐ Performance study vs. rate → Work in progress and seems quite difficult to extract reliable time resolution

- Electronics
- ☑ Test of integrated HV system
- ☑ Implementation of various trigger schemes
- ☐ Waveform & noise check
- ☐ Recording of waveform data

→ Several problems
- missing clock synchronization
- higher noise level than in lab(1.7mV→10mV)

- Laser Calibration System
- ☑ Implementation of laser calibration system
- ☐ Evaluate the accuracy of laser calibration system → Work in progress

- And .....
- ☑ To find unexpected problems towards physics run

Schedule

MEGII

Detector Installation

Engineering Run

Physics Run

2015

2016

2017 ~

$\mu \rightarrow e\gamma$ Discovery

Pilot Run 2015

Again

Pilot Run 2016

Analysis

Detector Construction

Timing Counter

JPS@Tohoku Gakuin Univ.

19日 CA会場　19pCA　13:30～17:00

素粒子実験領域
光検出器

1　MEG II実験のためのSiPMを用いた陽電子タイミングカウンターのシミュレーションによる性能評価
東大理
吉田昂平, 他MEG IIコラボレーション

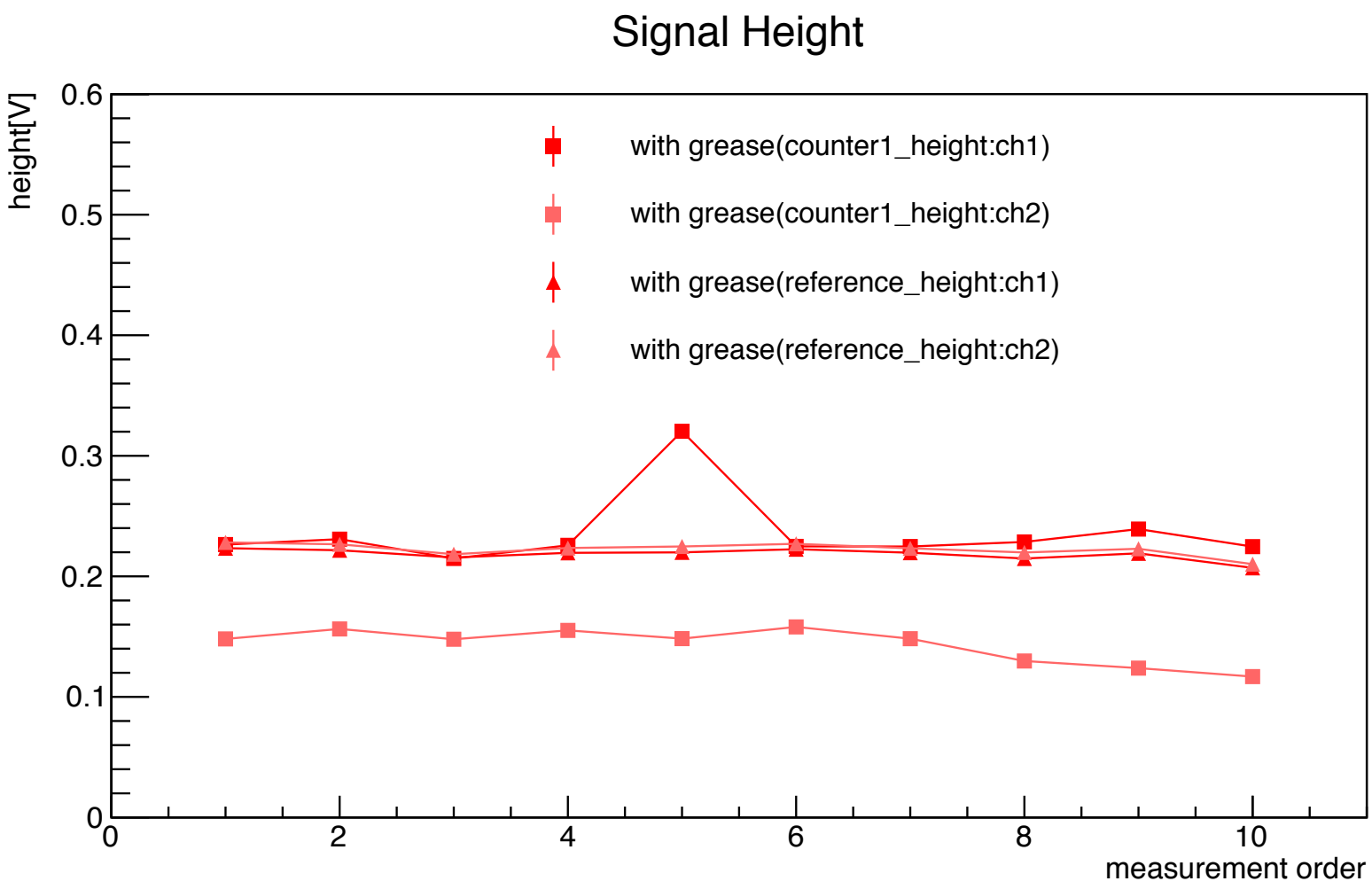
2　MEG II実験陽電子タイミングカウンターのコミッショニングーエンジニアリングラン最初の結果ー
東大理
西村美紀, 他MEG IIコラボレーション

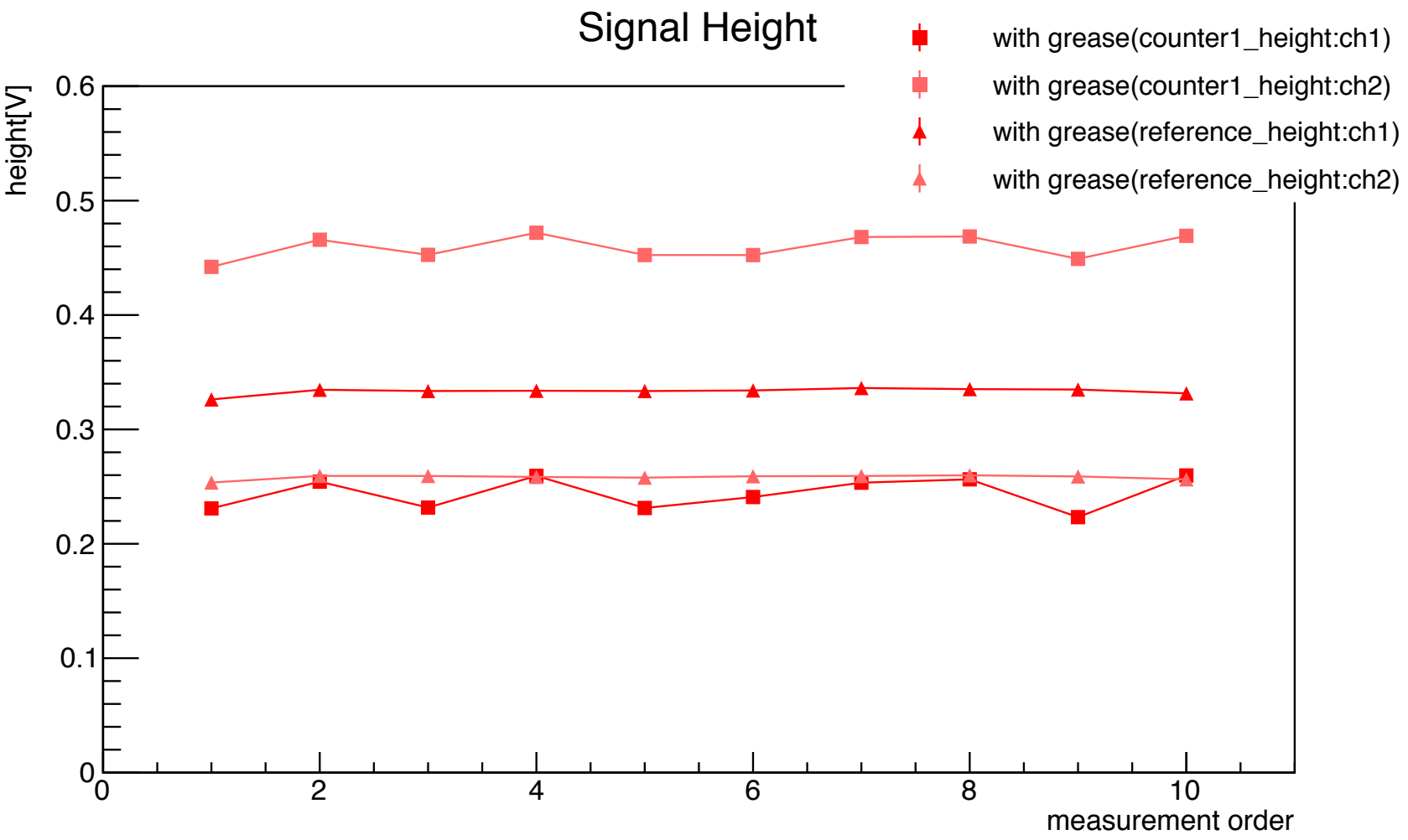
3　MEG II実験陽電子タイミングカウンターのコミッショニングー解析手法についてー
東大理
中尾光孝, 他 MEG IIコラボレーション

Summary

Introduction	❖The discovery of $\mu^+ \to e^+\gamma$ is New Physics. ❖MEG Ⅱ experiment: search for $\mu^+ \to e^+\gamma$ with unprecedented sensitivity from 2017.
Timing Counter	❖Positron Timing Counter can achieve 30ps～40ps time resolution. ❖Laser Calibration has successfully developed. ❖ 300 out of 512 were produced and 128 were already installed.
Pilot Run 2015 and The Future	❖Counter, HV and trigger worked well but for recording data. ❖ Analysis is ongoing and results will be presented in next JPS. ❖Next pilot run and full-installation follow.

Backup Slides

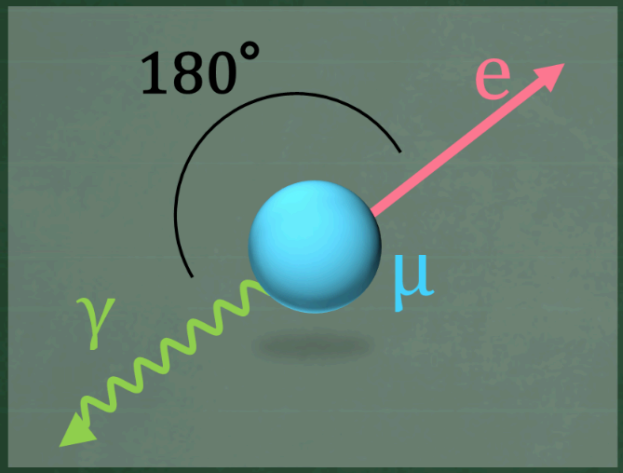

Signal Height
height[V]
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
8
10
measurement order
with grease(counter1_height:ch1)
with grease(counter1_height:ch2)
with grease(reference_height:ch1)
with grease(reference_height:ch2)


Signal Height
with grease(counter1_height:ch1)
with grease(counter1_height:ch2)
with grease(reference_height:ch1)
with grease(reference_height:ch2)
height[V]
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
8
10
measurement order

SignalとBackground

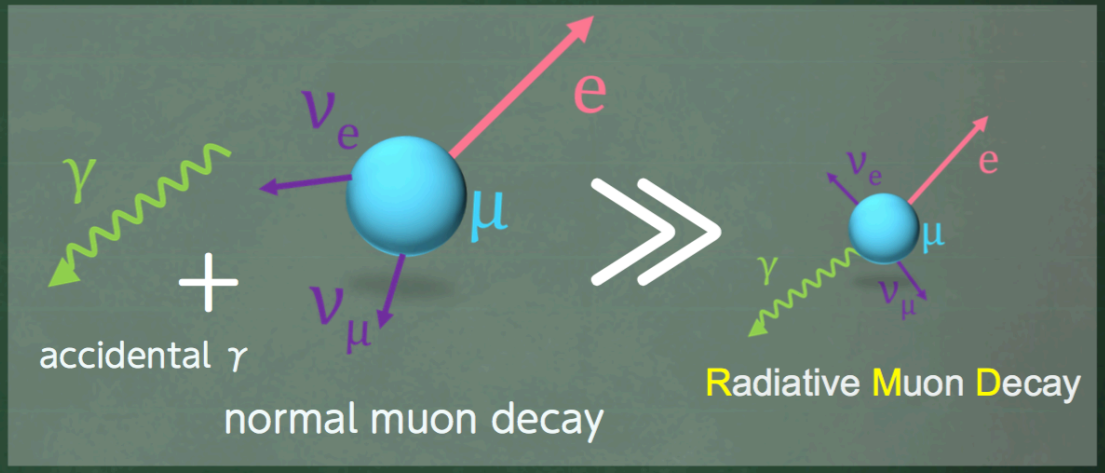
$\mu^+ \longrightarrow e^+\gamma$

SIGNAL



- 同時に反対方向
  ($\theta_{e\gamma}$=180°, T_γ=T_e)
- エネルギーは半分ずつ
  (E_γ,E_e=52.8MeV)

BACKGROUND

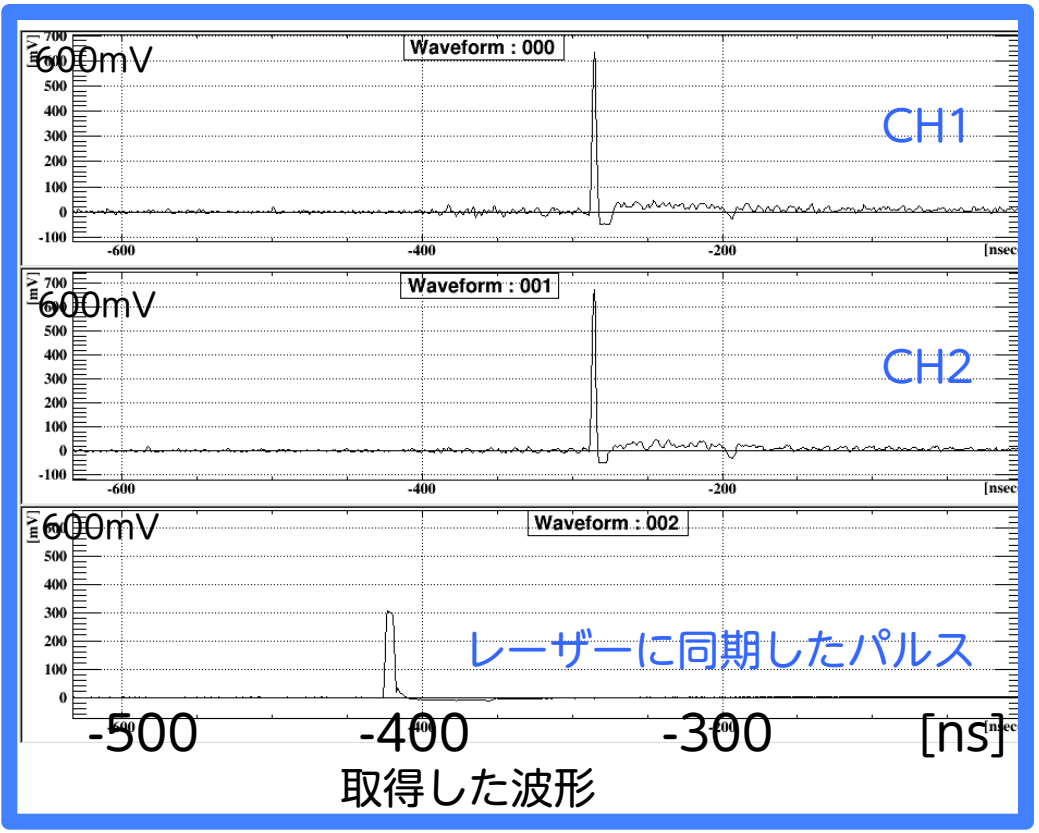


- 左が支配的
- accidental γの原因は、
  1.AIF(陽電子飛行中消滅)　or　2.RMD

要請

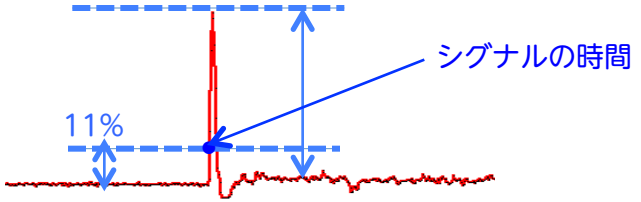
- 連続的・大強度ミューオンビーム→PSI
- γ検出器→高いエネルギー・位置・時間分解能
- 陽電子検出器→高い運動量分解能・高いrate下で耐えうる

解析手法



① ② ③ ④

- 各波形について、Heightの一定の割合のところをシグナルの時間とする(constant fraction time)。



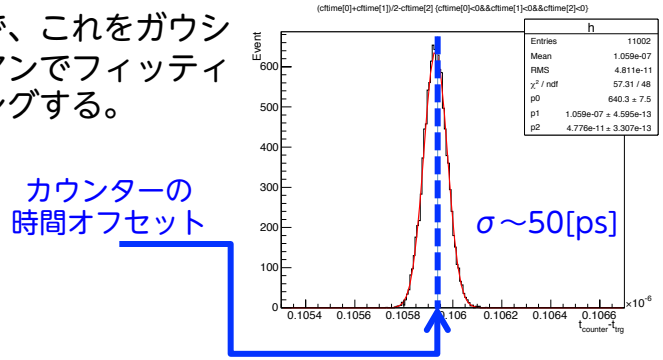
- CH1の時間(t_1)、CH2の時間(t_2)、レーザー同期パルスの時間(t_{sync})を得る。
- カウンターのヒット時間(t_{hit})は、

$$t_{hit} = \frac{t_1 + t_2}{2}$$

- カウンターの時間オフセット(t_{offset})は、

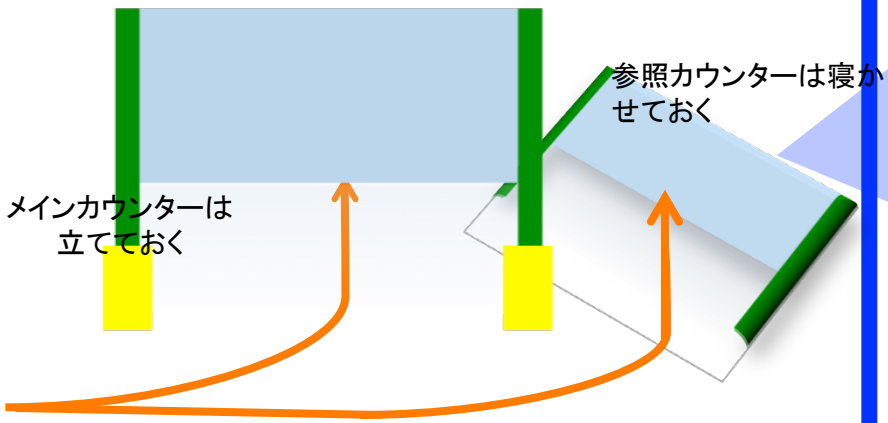
$$t_{timeoffset} = \frac{t_1 + t_2}{2} - t_{sync}$$

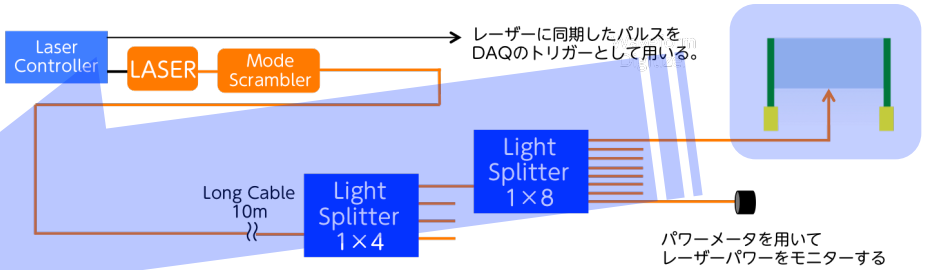
で、これをガウシアンでフィッティングする。



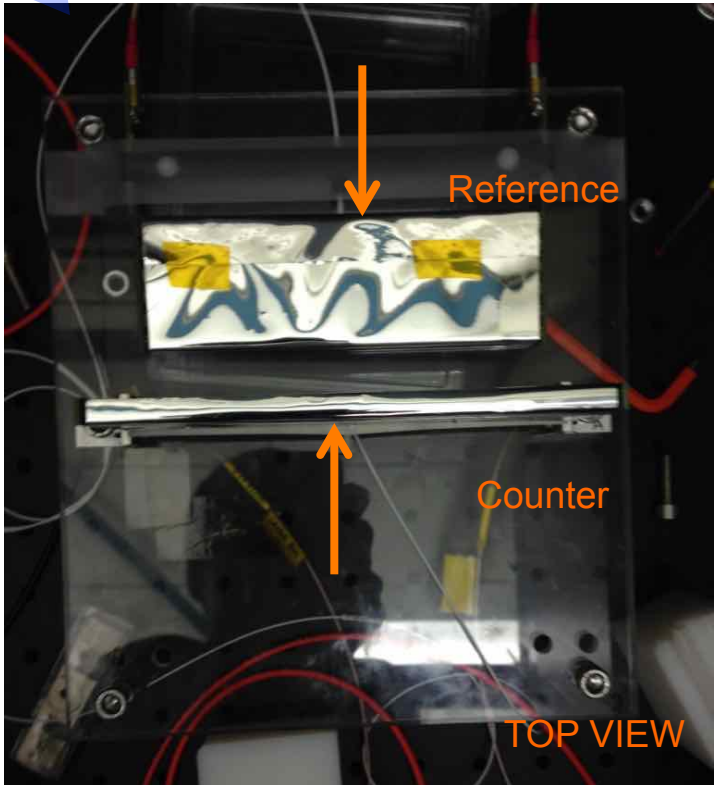
再現性テスト

Concept

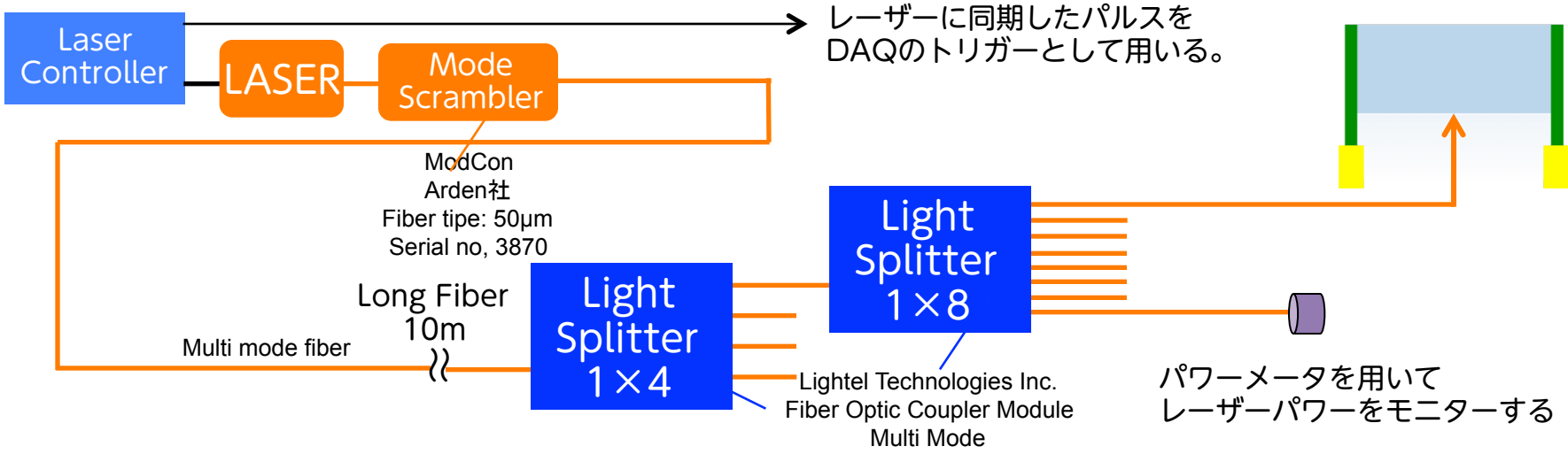


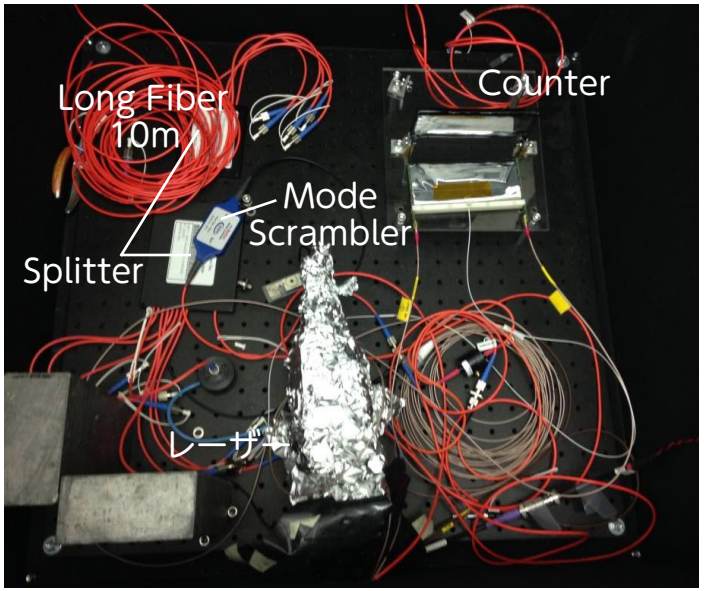


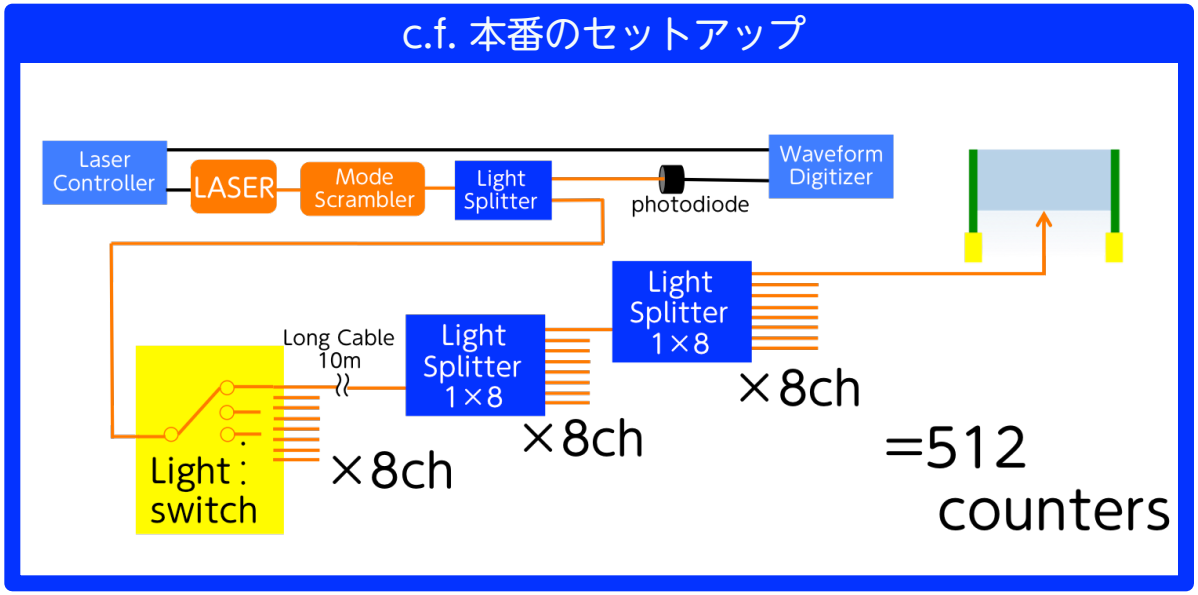
- ファイバーとカウンターのカップリングを次の2つで比較する。
  - 光学グリスなし
  - 光学グリスあり
- 抜き差しを繰り返し、時間オフセットのばらつきをみる。
- 温度変化やレーザーパワーによる変化を相殺するため、メインカウンターと参照カウンターの時間オフセットの差に注目する。
- 要請されるばらつきは $\sigma < 30$ps



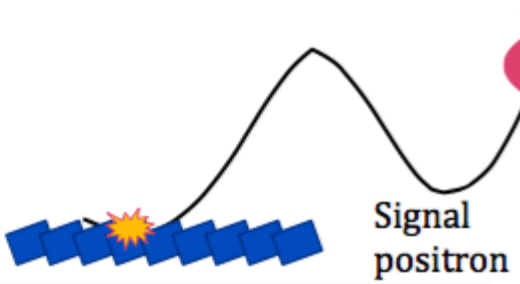
Laser Calibration Test Setup

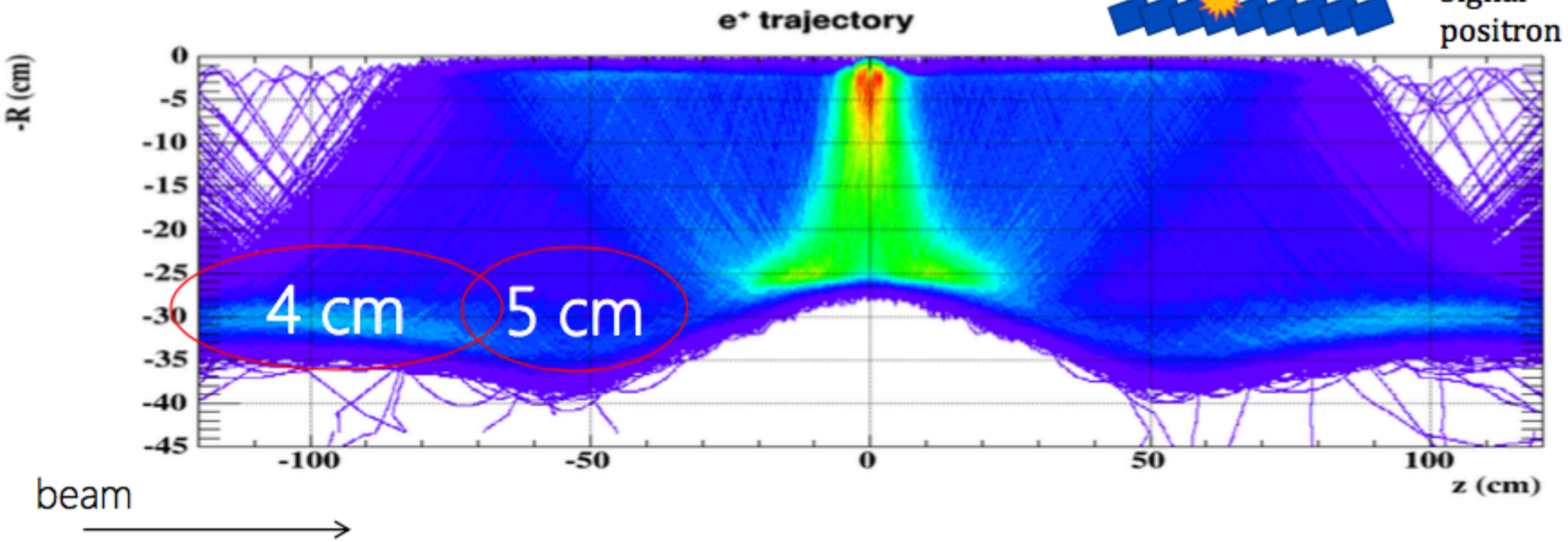




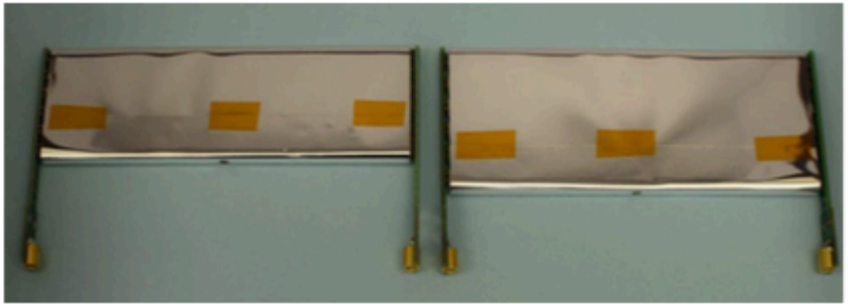


Counter Size Optimization





- 5 cm for positron spreading region.
- 4 cm for the other region.



Y. Uchiyama@VCI2016

Calibration Methods

- Time
- Gain
- Hit Position
- Counter Position

カウンター間の時間較正

時間較正

- 512個のカウンターは時間のオフセットをもっているので、30psの精度で時間を合わせる必要がある。
- ガンマ線検出器との時間合わせはミューオン輻射崩壊($\mu \to e\gamma\nu\nu$)を用いて行う。
- カウンター間の時間較正にはMichel CalibrationとLaser Calibrationという2つの独立な方法を用いて行う。

Michel Calibration

- MEGⅡ実験のメインのBGである、Michel崩壊($\mu \to e\nu\nu$)の陽電子を利用する。
- カウンターのヒット情報からクラスターをつくり、軌跡を再構成し、データカットを行う。
- 得られた軌跡毎にカウンターのTOFを計算する。
- 以下のχ^2を最小化するような、時間オフセットをカウンター毎に計算する。

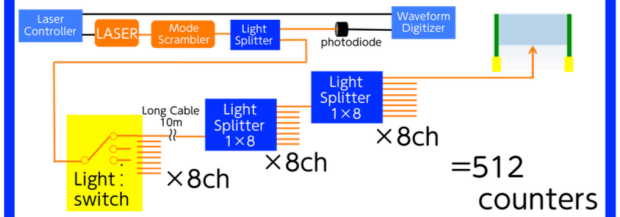
$$\chi^2 = \sum_{i}^{N_{ev}} \sum_{j}^{N_{hit}} \left(\left(T_{ij} - \left(T_{0i} + TOF_{ij} + \Delta T_j \right) \right) / \sigma \right)^2$$

測定時間 / 計算した時間 / カウンターに固有の時間オフセット

- すでにビームテストのデータを用いて確かめられた(西村,日本物理学会2014年秋季大会19pSG4)。

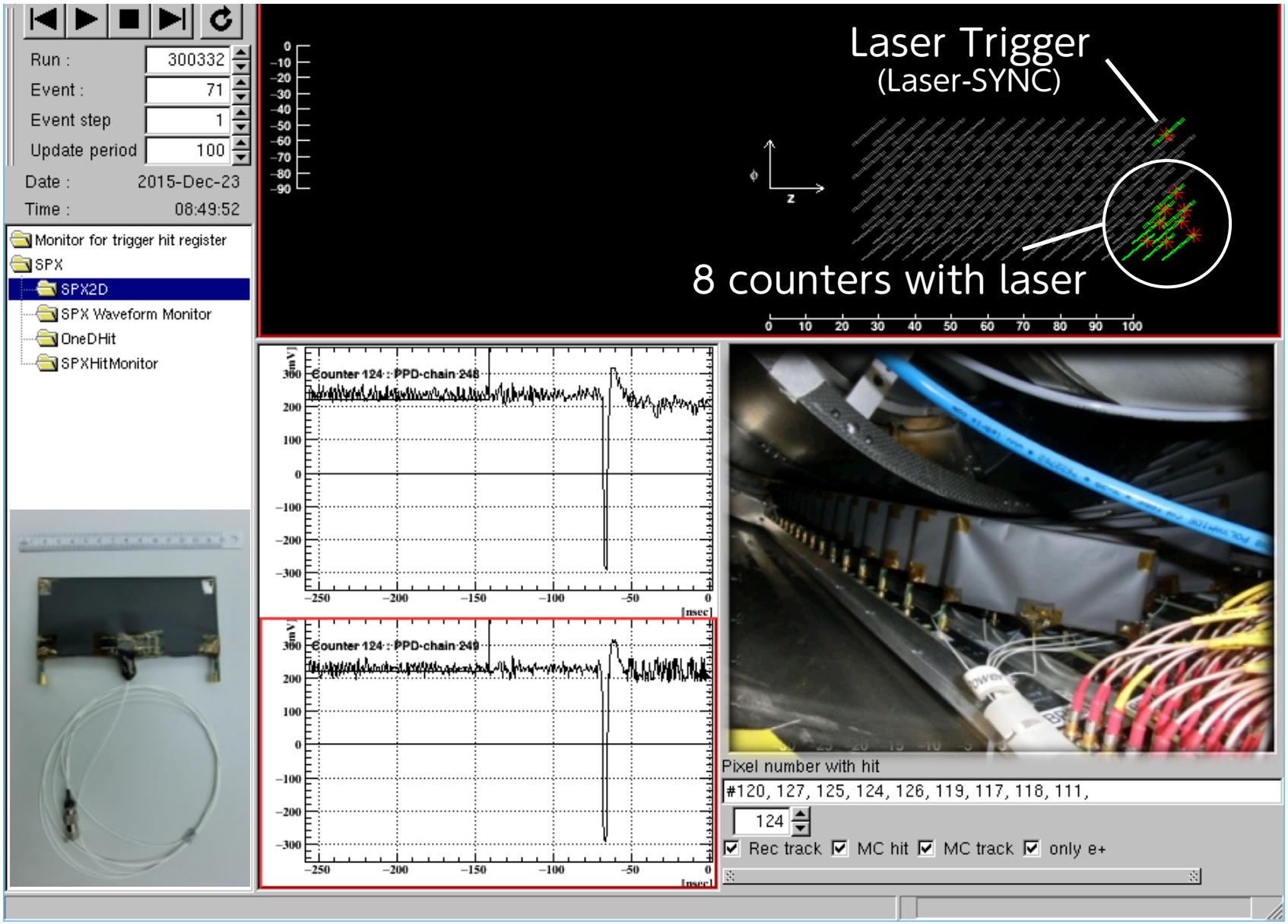
Laser Calibration

- 同じ光源から全カウンターにパルスレーザーを同時照射する。
- 以下の点で、Michel Calibrationと相補的な方法である。
  - 場所依存がない
  - データを貯める必要がない
  - 時間オフセットをモニターできる



日本物理学会2015年秋季大会(26aSN-2)

Laser Event


Run : 300332
Event : 71
Event step 1
Update period 100
Date : 2015-Dec-23
Time : 08:49:52
Monitor for trigger hit register
SPX
SPX2D
SPX Waveform Monitor
OneDHit
SPXHitMonitor
Laser Trigger
(Laser-SYNC)
8 counters with laser
Counter 124 : PPD-chain 248
Counter 124 : PPD-chain 249
[nsec]
Pixel number with hit
#120, 127, 125, 124, 126, 119, 117, 118, 111,
124
Rec track
MC hit
MC track
only e+

Trigger

TCB general features

- Five trigger types
  - *individual enable, pre-scale and scaler*
- TC triggers
  - *mask = 0: track-like*
  - *mask = 1: multiplicity*
  - *mask = 2: single tile*
- Auxiliary triggers
  - *mask = 3: laser*
  - *mask = 4: pedestal*
- Total and live time for rate measurements